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(54) **Optical wavelength conversion devices.**

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(56) References cited :
EP-A- 0 206 220
EP-A- 0 310 435
EP-A- 0 344 325
US-A- 3 822 927
PATENT ABSTRACTS OF JAPAN, vol. 13, no. 279 (P-891)[3627], 27th June 1989 ; & JP-A-168 735
PATENT ABSTRACTS OF JAPAN, vol. 13, no. 303 (P-896)[3651], 12th July 1989 ; & JP-A-177 034

(56) References cited :
PATENT ABSTRACTS OF JAPAN, vol. 8, no. 86 (P-269)[1523], 19th April 1984 ; & JP-A-592 008
PATENT ABSTRACTS OF JAPAN, vol. 11, no. 87 (P-557)[2534], 17th March 1987 ; & JP-A-61 240 207
PATENT ABSTRACTS OF JAPAN, vol. 9, no. 90 (P-360)[1813], 19th April 1985 ; & JP-A-59 218 406

(73) Proprietor : SONY CORPORATION
7-35 Kitashinagawa 6-chome
Shinagawa-ku
Tokyo 141 (JP)

(72) Inventor : Yamada, Masahiro c/o Patents Division Sony Corp.
6-7-35 Kitashinagawa
Shinagawa-ku Tokyo 141 (JP)

(74) Representative : Thomas, Christopher Hugo et al
D. Young & Co,
21 New Fetter Lane
London EC4A 1DA (GB)

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Description

This invention relates to optical wavelength conversion devices, and to processes for manufacturing such devices.

Previously there has been proposed an optical wavelength conversion device or secondary harmonic generator device (SHG device) comprising a waveguide utilizing Cerenkov radiation, and arranged as shown in Figure 5.

This SHG device has an optical waveguide 2 formed on the surface of a lithium niobate ($LiNbO_3$) single crystal substrate 1 by an ion exchange method using benzoic acid. A fundamental wave f enters one end of the waveguide 2 and a secondary harmonic (SH) wave s is emitted from the substrate 1. Thus a laser beam forming the fundamental wave f incident on an end face of the waveguide 2 is confined therein in a guided mode. The SH wave (SH light) s having one half the wavelength of the fundamental wave f is generated due to the non-linear optical effect of $LiNbO_3$ and the high energy density of the fundamental wave f.

By selecting a suitable thickness for the optical waveguide 2, the thus-generated SH light s is radiated in the depthwise direction of the substrate 1 at a certain angle δ, the Cerenkov angle in a radiation mode.

Another example of a secondary harmonic generator is disclosed in EP-A-0 206 220. This generator comprises a first optical waveguide having a structure which can guide a fundamental wave, and a second optical waveguide having a structure which can guide a secondary harmonic wave. The optical waveguides are optically connected with one another and are arranged in parallel on a substrate of non-linear optical material. The first and second waveguides have the same refractive index in order to enhance the conversion efficiency from the fundamental wave to the secondary harmonic wave.

Optical waveguides of different types have also been proposed, including the so-called ridge type waveguide which has a narrow strip-like ridge formed on a substrate as shown in Figure 6.

The ridge type waveguide has a laminated structure composed of a first substrate 11 with a refractive index n_1 and a second substrate 12 with a refractive index n_2, where $n_2 > n_1$. As light propagates, it is confined by the differences in the refractive indices between the substrates 11 and 12 in a direction vertical to the substrates 11 and 12, and by the difference in the refractive indices between the ridge 12a and air in a direction inward of the substrate plane. A ridge angle α is formed between the lateral side surface of the ridge 12a and the horizontal face of the substrate.

A ridge type waveguide as shown in Figure 6 can be formed by a selective growth or etching process. For instance, techniques of forming a ridge by a fine etching process were presented at the 1986 General National Meeting of the Society of Electronic Communications (Lecture No. 868). In this process, for example, Ti is first deposited on a substrate of $LiNbO_3$ to form a metal layer thereon, and then a layer of photoresist which has a trade name of "AZ-1350J" is selectively formed on the metal layer by photo lithography, followed by patterning of the metal layer by wet etching using the photoresist layer as a mask. Thereafter, the photoresist layer is removed, and the metal layer which remains as a result of the patterning is used as a mask to form a ridge on the substrate by electronic cyclotron resonance-reactive ion etching (ECR-RIE) using C_3F_8 as an etching gas.

Such an SHG device, however, has the drawback that the beam of SH light s is emitted in a crescent shape in section as shown in Figure 5, instead of in a circular shape which is desirable. Thus, taking a light source for a high density optical recording medium or a laser printer as an example of an application of the SHG device, the light source is required to be able to emit a beam of a circular or elliptical shape rather than a beam of crescent shape, which would lower the efficiency of utilization.

Although it might seem possible to reform the emitted SH light beam from a crescent shape into a circular or elliptical shape, this has been found to be extremely difficult because the SH light tends to sink into the deep portions depthwise of the substrate.

With a ridge type waveguide as shown in Figure 6, in order to obtain high output, it is necessary to make the ridge angle α as close to 90° as possible, and to form smooth surfaces on the lateral sides of the ridge by the ECR-RIE process. These requirements have to be met because a smaller ridge angle will result in lower efficiency in confining light within the ridge, while rough side surfaces of the ridge will increase the light propagation loss by scattering. However, by making the ridge angle α close to 90°, it becomes possible not only to reduce this tendency but also to attain a higher integration of optical integrated circuit devices with ridge type waveguides.

Nevertheless, the ridge angles which have been achieved are 70° to 80° at most, which is insufficient for efficient light confining. Moreover, the suppression of surface roughening has been insufficient. Especially in the case of the techniques which use a so-called lift-off process, the side surfaces of a formed metal layer are susceptible to bruises or blemishes which will be reflected by roughening of the side surfaces of a ridge when the metal layer is subsequently used as a mask in a ridge-forming process.

Moreover, the ratio of the etch rate (that is, the selectivity ratio of etching) of the crystal substrate to that

of the mask metal is approximately as small as 2 to 3, which is not necessarily sufficient in terms of the economy, reliability and productivity of the process.

According to one aspect of the present invention there is provided an optical wavelength conversion device comprising: an optical waveguide formed on a substrate of a non-linear optical material so as to generate a secondary harmonic wave by Cerenkov radiation, the waveguide comprising a first waveguide passage for confining a fundamental wave and converting it into a secondary harmonic wave, and a second waveguide passage for confining said secondary harmonic wave and propagating it towards an end face for emission therefrom,

characterised in that:

said waveguide is formed in a ridge shape on said substrate, and said first waveguide passage is formed so as to be in contact with said second waveguide passage along at least one of the lateral sides of the ridge; and in that $n_2 > n_3 > n_1$, where n_1, n_2 and n_3 are, respectively, the refractive indices of said substrate, said first waveguide passage and said second waveguide passage; and in that said first and second waveguide passages are formed so as to satisfy:

$$W_rf < a < W_rs,$$
$$W_rf \text{ or } W_rs < b,$$

and

$$W_rs < c$$

where a is the width of said first waveguide passage in a direction which is parallel to said substrate, b is the depth of said first waveguide passage in a direction which is perpendicular to the face of said substrate, c is the depth of said second waveguide passage in a direction which is perpendicular to the face of said substrate, W_rf is the fundamental wave cut-off thickness below which propagation of the fundamental wave is prevented, and W_rs is the secondary harmonic wave cut-off thickness below which propagation of the secondary harmonic wave is prevented.

According to another aspect of the present invention there is provided a process for manufacturing such an optical wavelength conversion device, comprising the steps of:

forming, on a substrate of a non-linear optical material which has a refractive index n_1, an optical waveguide layer which is to be used as a second waveguide passage and which has a refractive index n_3 ($n_3 > n_1$) by diffusion of titanium;

forming a metal layer on said substrate;

selectively forming a photoresist layer on said metal layer;

selectively removing said metal layer where it is not masked with said photoresist layer using electron cyclotron resonance etching with argon gas;

removing said photoresist layer;

etching out a ridge on said substrate using said metal layer as a mask by electron cyclotron resonance etching using a fluorocarbon gas;

forming, on a lateral side of said optical waveguide layer, a proton exchange layer which is to be used as a first waveguide passage and which has a refractive index n_2 ($n_2 > n_3 > n_1$), by a heat treatment in an aqueous solution capable of proton exchange with optical waveguide portions which are exposed by removal of said metal layer; and

removing the remaining portions of said metal layer.

According to a further aspect of the present invention there is provided a process for manufacturing such an optical wavelength conversion device, comprising the steps of:

forming, on a substrate of a non-linear optical material which has a refractive index n_1, an optical waveguide layer which is to be used as a second waveguide passage and which has a refractive index n_3 ($n_3 > n_1$) by diffusion of titanium;

forming a metal layer on said substrate;

selectively forming a photoresist layer on said metal layer;

selectively removing a part of said metal layer and said optical waveguide layer, using said photoresist layer as a mask;

forming, on a lateral side of said optical waveguide layer, a proton exchange layer which is to be used as a first waveguide passage and which has a refractive index n_2 ($n_2 > n_3 > n_1$), by a heat treatment in an aqueous solution capable of proton exchange with optical waveguide portions which are exposed by removal of said metal layer;

etching said proton exchange layer into a thin layer by reactive ion etching using selectively unremoved portions of said metal layer as a mask; and

removing the remaining portions of said metal layer.

The invention will now be described by way of example with reference to the accompanying drawings,

throughout which like parts are referred to by like references, and in which:

Figure 1 is a perspective view of an embodiment of optical wavelength conversion device according to the present invention;

Figures 2 and 3 are diagrams for explaining the embodiment;

Figure 4 is a diagram illustrating a process for manufacturing the device; and

Figures 5 and 6 are perspective views of previously proposed optical wavelength conversion devices.

Observations which have led to the present invention will first be explained.

The beam shape of the secondary harmonic wave which is emitted from an optical wavelength conversion device varies depending upon the condition of propagation of the Cerenkov radiation within the device, and the condition of propagation can be varied by changing the shape of the waveguide. It follows that the beam of the secondary harmonic wave emitted from the device could be reformed into a circular or elliptical shape by employing a waveguide of a suitable shape.

A question arises as to what shape is suitable for the waveguide for this purpose. First, considering a slab type waveguide which has, for simplicity of explanation, a film-like optical waveguide 2 formed on the surface of a substrate 1 as shown in Figure 2, the propagation of light through the optical waveguide becomes difficult if the thickness w of the waveguide 2 becomes smaller than a certain value which is determined depending upon the material of the substrate 1, the manufacturing process of the optical waveguide 2 and the optical wavelength. Namely, the propagation of light through the optical waveguide is possible when the thickness w of the waveguide 2 is greater than a certain thickness.

For example, Figure 3 diagrammatically shows an optical waveguide 2 which is formed on a substrate 1 of a non-linear optical material such as single crystal $LiNbO_3$. The optical waveguide 2 has a sectional shape with a thickness a in the direction parallel to the surface of the substrate 1, and a thickness b in the depthwise direction of the substrate 1. In this instance, by forming the optical waveguide 2 in a sectional shape where the thicknesses a and b are greater than thicknesses which prevent the propagation of the fundamental wave, namely, greater than a cut-off thickness W_rf of the fundamental wave, the thickness a is smaller than the secondary harmonic wave cut-off thickness W_rs, and the thickness b is larger than the secondary harmonic cut-off thickness W_rs, the secondary harmonic wave can be propagated parallel to the surface of the substrate 1 without propagation in the depthwise direction of the substrate 1.

Figure 1 shows an embodiment of the invention, which has an optical waveguide 2 formed on a substrate 1 of single crystal $LiNbO_3$, in a shape which satisfies the conditions which will be discussed.

More specifically, the substrate 1 has a ridge type optical waveguide 2 formed in a ridge portion l_1. The optical waveguide 2 is composed of first waveguide passages 2a and 2c which are formed symmetrically in the opposite side portions of the ridge l_1, and a second waveguide passage 2b which is formed between the first waveguide passages 2a and 2c. the first waveguide passages 2a and 2c and the second waveguide passage 2b, each have a required refractive index. The first waveguide passages are dimensioned so that:

$$W_rf < a < W_rs$$

$$W_rf \text{ or } W_rs < b$$

where a is the width of the first waveguide passages 2a and 2c in a direction parallel to the surface of the ridge portion l_1, namely, in the direction of x; b is the thickness (or height) of the first waveguide passages 2a and 2c in a direction parallel to lateral side surfaces of the ridge portion l_1, or in the direction of y; W_rf is the fundamental wave cut-off thickness, and W_rs is the secondary harmonic wave cut-off thickness of the waveguide. The fundamental wave is confined in both the x and y directions, while the secondary harmonic wave is confined in the y direction but is radiated in the x direction.

The second waveguide member 2b is formed in a ridge structure which is greater than the secondary harmonic wave cut-off thickness W_rs in thickness, or of thickness c in the y direction, satisfying:

$$W_rs < c$$

and which confines the secondary harmonic wave in both the y and x directions.

Upon irradiating a laser beam on one end face of the optical wavelength conversion device of this embodiment with the above-described construction, the laser light is condensed towards both or one of the end faces of the first waveguide 2a and 2c and the second waveguide 2b, and is confined in both or one of the first waveguide 2a and 2c and the second waveguide 2b.

Due to the energy density of the laser light itself and the non-linear optical effect of the waveguide and substrate 1, the confined laser light is efficiently converted into a wave which is one half the wavelength of the fundamental wave, namely, into a secondary harmonic wave (SH light), is confined in the waveguide including the first and second waveguide passages 2a to 2c, is propagated in the z-direction in the guided mode or by repeated reflections between the first and second waveguide passages 2a and 2c, and is emitted from the opposite end face of the secondary wave in the form of a beam of a circular or elliptic shape.

If desired, either one of the first waveguide passages 2a and 2c of the above-described embodiment may

be omitted. Even in such a case, the secondary harmonic wave can be generated in a similar manner.

An example of the process for manufacturing this optical wavelength conversion device will be described with reference to Figures 4A to 4G.

First, a titanium diffusion layer l_{T1} formed on the front surface of the $LiNbO_3$ substrate 1 by diffusion of Ti as shown in Figure 4A.

A masking metal layer 3 (of Ni, Cu, Ta, Ti or the like) is then formed on the front surface of the substrate 1 by vapour deposition as shown in (Figure 4B), and a resist 4 is coated thereon in a predetermined pattern as shown in Figure 4C.

Then, as shown in Figure 4D, the front side of the substrate 1 is subjected to ECR-RIE (electron cyclotron resonance-reactive ion etching, that is, reactive ion etching which utilizes the phenomenon of electron cyclotron resonance) using CF_4, C_2F_6, C_3F_8, CHF or a like fluorocarbon as an etching gas. As a result of this etching, the mask layer 3, except those portions which underlie the resist 4, and the surface portions of the titanium diffusion layer l_{T1} are removed. The mask layer portion 3 which lies under the resist 4 remains to serve as a mask 3a.

Alternatively, a ridge can be formed by a two-stage etching process, namely, a process consisting of a stage of etching a metal layer by the use of argon and a stage of etching the substrate surface with the resulting masking metal layer by the use of a fluorocarbon gas. Accordingly, the masking metal layer should have properties which permit easy etching by argon gas but have sufficient resistance to the fluorocarbon gas to be used. On the other hand, the substrate should have properties which ensure sufficient resistance to argon gas but permit easy etching by the fluorocarbon gas used.

Table 1 below shows the etch rates of various substances by argon gas in comparison with etch rates by CF_4 gas, taken as an example of fluorocarbon gases. The substances shown here include $LiNiO_3$ which is widely used as a non-linear optical material for the substrate, and Ta, Ti, Ag, Al, Ni and Cu which are used as a masking metal. As a reference, etch rates of known photoresists, TSMR8900 and AZ4210 (products of Tokyo Ohka Kogyo), are also shown in the table.

Table 1

Substance Etched	Etch Rate (10^{-10} m/min)	
	Argon	CF_4
$LiNiO_3$	30	110
Ta	45	>110
Ti	15	>110
Ag	360	>110
Al	15	52
Ni	80	10
Cu	220	15
TSMR8900	105	300
AZ42210	220	400

Each of the etching stages using either argon or a fluorocarbon gas is carried out by means of an electron cyclotron resonance type etching (ECR etching) apparatus, which utilizes the phenomenon that, when the cyclotron angular frequency of electrons in circular motion in a magnetic field come into synchronism with the angular frequency of an electric field or microwaves introduced through a wave tube, the electrons are accelerated by resonantly absorbing the microwave energy, efficiently producing plasma through collision against neutral molecules and ionization. With an ECR etching apparatus, an ion beam of good directivity can be obtained at a gas pressure as low as 1.3×10^{-2} Pa, so that it is possible to carry out the etching in a stable manner against reactive gases, and coupled with advantages such as high accuracy of etching shape and the improbability of re-decomposition and re-deposition of reaction products. The ECR etching can be carried out under generally acceptable conditions, for example, with a gas flow rate of 2 SCCM, a gas pressure of 1.3×10^{-3} to

1.3×10^{-1} Pa, a microwave power of 200 W, and an acceleration voltage of 400 V.

Thus, by selecting and combining suitable kinds of photoresist, metals and etching gases, a ridge having a ridge angle α close to 90° can be formed on the substrate by the ECR etching with excellent directivity, and through the utilization of the properties of the respective materials.

The feasibility of the above-described ridge-forming process leads to realization of a SHG device which has, along one lateral side of the ridge, a region with a refractive index which is higher than that of the ridge which can serve as a first waveguide for propagating a fundamental wave (radiated directly from a light source), and, in the remaining ridge portion, a second waveguide is formed for propagating the secondary harmonic wave radiated from the region of higher refractive index. When such an SHG device has a ridge angle of approximately 90°, it can efficiently confine into the ridge the secondary harmonic wave which is radiated from the above-mentioned region at a predetermined Cerenkov angle.

In a heat treatment in pyrophosphoric acid, benzoic acid or the like, proton exchange occurs to the exposed surface portions of the titanium diffusion layer I_{T1}, as well as in the opposite side portions of the titanium diffusion layer I_{T1} under the mask 3a for forming a proton exchange layer 5 (Figure 4E). In this treatment, the resist 4 is removed.

Then, the workpiece is subjected to etching again in an ECR-RIE apparatus. This time, the proton exchange layer 5 is etched only at its surface portions which are exposed by the mask 3a, and as a result a thin proton exchange layer 5 remains on the exposed surface portions.

In this stage of etching, the exposed portions of the proton exchange layer 5 may be totally removed if desired.

Then the mask 3a is removed as shown in Figure 4G. After the removal of the mask 3a, there is obtained an optical wavelength conversion device as shown In Figure 1, with first waveguide passages 2a and 2c constituted by the exposed portions of the proton exchange layer 5 and a second waveguide passage 2b constituted by the titanium diffusion layer I_{T1} between the first waveguide passages 2a and 2c.

With this arrangement, the fundamental wave is efficiently converted into the secondary harmonic wave , which is then emitted in the form of a beam having a circular or elliptical shape in section. This beam of improved shape can be applied widely and efficiently as a light source in high density optical recording, as a light source for a laser printer, and so forth.

Moreover, the process described makes it possible to form a ridge type waveguide with a ridge angle α of approximately 90° which has smooth side surfaces. Accordingly, it becomes possible to suppress the light propagation loss to an extremely low level and to enhance the degree of circuit integration. Besides, the laser light beam of a circular or elliptical shape, which is obtained from the ridge type wave guide of the above-described construction, it is extremely suitable for application to an optical disc system, laser printer or the like. Further, since an ECR etching apparatus can be commonly used for patterning a metal layer and for shaping a ridge on a substrate, improvements in production also result due to the manufacturing techniques.

Claims

1. An optical wavelength conversion device comprising:
an optical waveguide (2) formed on a substrate (1) of a non-linear optical material so as to generate a secondary harmonic wave by Cerenkov radiation, the waveguide (2) comprising a first waveguide passage (2a, 2c) for confining a fundamental wave and converting it into a secondary harmonic wave, and a second waveguide passage (2b) for confining said secondary harmonic wave and propagating it towards an end face for emission therefrom,
characterised in that:
said waveguide (2) is formed in a ridge shape on said substrate (1), and said first waveguide passage (2a, 2c) is formed so as to be in contact with said second waveguide passage (2b) along at least one of the lateral sides of the ridge; and in that $n_2 > n_3 > n_1$, where n_1, n_2 and n_3 are, respectively, the refractive indices of said substrate (1), said first waveguide passage (2a, 2c) and said second waveguide passage (2b); and in that said first and second waveguide passages (2a, 2c, 2b) are formed so as to satisfy:

$$W_r f < a < W_r s,$$
$$W_r f \text{ or } W_r s < b,$$

and

$$W_r s < c$$

where a is the width of said first waveguide passage (2a, 2c) in a direction which is parallel to said substrate (1), b is the depth of said first waveguide passage (2a, 2c) in a direction which is perpendicular to the face of said substrate (1), c is the depth of said second waveguide passage (2b) in a direction which

is perpendicular to the face of said substrate (1), W_rf is the fundamental wave cut-off thickness below which propagation of the fundamental wave is prevented, and W_rs is the secondary harmonic wave cut-off thickness below which propagation of the secondary harmonic wave is prevented.

2. A process for manufacturing an optical wavelength conversion device according to claim 1, comprising the steps of:
forming, on a substrate (1) of a non-linear optical material which has a refractive index n1, an optical waveguide layer (1_{Ti}) which is to be used as a second waveguide passage (2b) and which has a refractive index n_3 ($n_3 > n_1$) by diffusion of titanium;
forming a metal layer (3) on said substrate (1);
selectively forming a photoresist layer (4) on said metal layer (3); selectively removing said metal layer (3) where it is not masked with said photoresist layer (4) using electron cyclotron resonance etching with argon gas;
removing said photoresist layer (4);
etching out a ridge on said substrate (1) using said metal layer (3) as a mask (3a) by electron cyclotron resonance etching using a fluorocarbon gas;
forming, on a lateral side of said optical waveguide layer (2), a proton exchange layer (5) which is to be used as a first waveguide passage (2a, 2c) and which has a refractive index n_2 ($n_2 > n_3 > n_1$), by a heat treatment in an aqueous solution capable of proton exchange with optical waveguide portions which are exposed by removal of said metal layer (3); and
removing the remaining portions of said metal layer (3).

3. A process for manufacturing an optical wavelength conversion device according to claim 1, comprising the steps of:
forming, on a substrate (1) of a non-linear optical material which has a refractive index n1, an optical waveguide layer (1_{Ti}) which is to be used as a second waveguide passage (2b) and which has a refractive index n_3 ($n_3 > n_1$) by diffusion of titanium;
forming a metal layer (3) on said substrate (1);
selectively forming a photoresist layer (4) on said metal layer (3);
selectively removing a part of said metal layer (3) and said optical waveguide layer (2), using said photoresist layer (4) as a mask;
forming, on a lateral side of said optical waveguide layer (2), a proton exchange layer (5) which is to be used as a first waveguide passage (2a, 2c) and which has a refractive index n_2 ($n_2 > n_3 > n_1$), by a heat treatment in an aqueous solution capable of proton exchange with optical waveguide portions which are exposed by removal of said metal layer (3);
etching said proton exchange layer (5) into a thin layer by reactive ion etching using selectively unremoved portions of said metal layer (3) as a mask (3a); and
removing the remaining portions of said metal layer (3).

Patentansprüche

1. Vorrichtung zur Umwandlung von optischen Wellenlängen, die folgendes enthält:
einen auf einem Substrat (1) aus einem nichtlinearen optischen Material ausgebildeten optischen Wellenleiter (2), um eine sekundäre harmonische Welle durch Tscherenkow-Strahlung zu erzeugen, wobei der Wellenleiter (2) einen ersten Wellenleiterdurchgang (2a, 2c) zur Begrenzung (Confinement) einer Grundwelle und zu deren Umwandlung in eine sekundäre harmonische Welle enthält, und einen zweiten Wellenleiterdurchgang (2b) zur Begrenzung besagter sekundärer harmonischer Welle und zu deren Ausbreitung in Richtung auf eine Stirnfläche, um von dort emittiert zu werden,
dadurch **gekennzeichnet,**
daß der besagte Wellenleiter (2) stegförmig auf dem besagten Substrat (1) ausgebildet ist und der erste Wellenleiterdurchgang (2a, 2c) derart ausgebildet ist, um in Kontakt mit dem zweiten Wellenleiterdurchgang (2b) entlang zumindest einer der lateralen Seiten des Steges zu sein, und daß $n_2 > n_3 > n_1$ ist, wobei n_1, n_2 und n_3 die entsprechenden Brechungsindizes des Stubstrates (1), des ersten Wellenleiterdurchganges (2a, 2c) und des zweiten Wellenleiterdurchgangs (2b) sind und daß der erste und der zweite Wellenleiterdurchgang (2a, 2c, 2b) derart ausgebildet sind, daß folgende Bedingungen erfüllt sind:

$$W_rf < a < W_rs$$
$$W_rf \text{ oder } W_rs < b,$$

und

$$W_r s < c$$

wobei a die Breite des ersten Wellenleiterdurchganges (2a, 2c) in einer zu dem Substrat (1) parallelen Richtung bedeutet, b die Tiefe des ersten Wellenleiterdurchganges (2a, 2c) in einer senkrecht zu der Oberseite des Substrates (1) liegenden Richtung bedeutet, c die Tiefe des zweiten Wellenleiterdurchganges (2b) in einer senkrecht zu der Oberseite des Substrates (1) liegenden Richtung bedeutet, $W_r f$ die Grenzstärke der Grundwelle bedeutet, unterhalb der die Ausbreitung der Grundwelle verhindert wird und $W_r s$ die Grenzstärke der sekundären harmonischen Welle bedeutet, unterhalb der die Ausbreitung der sekundären harmonischen Welle verhindert wird.

2. Verfahren zur Herstellung einer Vorrichtung zur Umwandlung von optischen Wellenlängen nach Anspruch 1, das folgende Schritte enthält:
Ausbildung einer optischen Wellenleiterschicht (1_{Ti}), die als zweiter Wellenleiterdurchgang (2b) verwendet wird und die einen Brechungsindex n_3 ($n_3 > n_1$) hat, durch Diffusion von Titan auf einem Substrat (1) eines nichtlinearen optischen Materiales, das einen Brechungsindex von n_1 aufweist;
Ausbildung einer Metallschicht (3) auf dem Substrat (1);
selektive Ausbildung einer Photolackschicht (4) auf der Metallschicht (3);
selektive Entfernung der Metallschicht (3) an den nicht durch die Maske mit der Photolackschicht (4) bedeckten Bereichen unter Einsatz von Elektronen-Zyklotronresonanz-Ätzen mit Argongas;
Entfernung der Photolackschicht (4);
Herausätzen eines Steges auf dem Substrat (1) unter Verwendung der Metallschicht (3) als Maske (3a) durch Elektronen-Zyklotronresonanz-Ätzen unter Verwendung eines Fluorkohlenstoffgases;
Ausbildung einer Protonenaustauschschicht (5), die als ein erster Wellenleiterdurchgang (2a, 2c) verwendet wird und die einen Brechungsindex n_2 ($n_2 > n_3 > n_1$) hat, auf einer lateralen Seite der optischen Wellenleiterschicht (2), durch eine Wärmebehandlung in einer wässrigen Lösung, die einen Protonenaustausch mit Bereichen des optischen Wellenleiters ermöglicht, die durch die Entfernung der Metallschicht (3) freigelegt werden; und
Entfernung der verbleibenden Bereiche der Metallschicht (3).

3. Verfahren zur Herstellung einer Vorrichtung zur Umwandlung von optischen Wellenlängen nach Anspruch 1, das folgende Schritte enthält:
Ausbildung einer optischen Wellenleiterschicht (1_{Ti}) zum Einsatz als ein zweiter Wellenleiterdurchgang (2b), die einen Brechungsindex n_3 ($n_3 > n_1$) hat, durch Diffusion von Titan auf einem Substrat (1) eines nichtlinearen optischen Materiales, das einen Brechungsindex n_1 aufweist;
Ausbildung einer Metallschicht (3) auf dem Substrat (1);
selektive Ausbildung einer Photolackschicht (4) auf der Metallschicht (3);
selektive Entfernung eines Teiles der Metallschicht (3) und der besagten optischen Wellenleiterschicht (2) unter Verwendung der besagten Photolackschicht (4) als Maske;
Ausbildung einer Protonenaustauschschicht (5), die als ein erster Wellenleiterdurchgang (2a, 2c) eingesetzt wird und die einen Brechungsindex n_2 ($n_2 > n_3 > n_1$) aufweist, auf einer lateralen Seite der optischen Wellenleiterschicht (2), durch eine Wärmebehandlung in einer wässrigen Lösung, die einen Protonenaustausch mit Bereichen des optischen Wellenleiters ermöglicht, die durch die Entfernung der Metallschicht (3) freigelegt werden;
Ätzen der Protonenaustauschschicht (5) zu einer Dünnschicht durch reaktives Ionenätzen unter Verwendung selektiv nicht entfernter Bereiche der Metallschicht (3) als Maske (3a); und
Entfernung der verbleibenden Bereiche der Metallschicht (3).

Revendications

1. Dispositif de conversion de longueur d'onde optique comprenant :

un guide d'onde optique (2) formé sur un substrat (1) d'une matière optique non linéaire de manière à produire une onde harmonique de rang 2 par rayonnement de Cerenkov, le guide d'onde (2) comprenant un premier conduit de guide d'onde (2a, 2c) pour confiner une onde fondamentale et pour la convertir en une onde harmonique de rang 2, et un second conduit de guide d'onde (2b) pour confiner ladite onde harmonique de rang 2 et pour la propager en direction d'une face d'extrémité pour l'émettre ;

caractérisé en ce que :

ledit guide d'onde (2) est formé en une forme nervurée sur ledit substrat (1), et ledit premier conduit

de guide d'onde (2a, 2c) est formé de manière à être en contact avec ledit second conduit de guide d'onde (2b) le long d'au moins l'une des faces latérales de la nervure ; et en ce que $n_2 > n_3 > n_1$, où n_1, n_2 et n_3 sont, respectivement, les indices de réfraction dudit substrat (1), dudit premier conduit de guide d'onde (2a, 2c) et dudit second conduit de guide d'onde (2b) ; et en ce que lesdits premier et second conduits de guide d'onde (2a, 2c, 2b) sont formés de manière à satisfaire :

$$W_r f < a < W_r s,$$
$$W_r f \text{ ou } W_r s < b,$$

et

$$W_r s < c$$

où a est la largeur dudit premier conduit de guide d'onde (2a, 2c) dans une direction qui est parallèle audit substrat (1), b est la profondeur dudit premier conduit de guide d'onde (2a, 2c) dans une direction qui est perpendiculaire à la face dudit substrat (1), c est la profondeur dudit second conduit de guide d'onde (2b) dans une direction qui est perpendiculaire à la face dudit substrat (1), $W_r f$ est l'épaisseur de coupure d'onde fondamentale au-dessous de laquelle la propagation de l'onde fondamentale est impossible, et $W_r s$ est l'épaisseur de coupure d'onde harmonique de rang 2 au-dessous de laquelle la propagation de l'onde harmonique de rang 2 est impossible.

2. Procédé de fabrication d'un dispositif de conversion de longueur d'onde optique selon la revendication 1, comprenant les étapes :

de formation, sur un substrat (1), fait d'une matière optique non linéaire qui a un indice de réfraction n_1, par diffusion de titane, d'une couche de guide d'onde optique (1_{Ti}) qui est destinée à être utilisée comme un second conduit de guide d'onde (2b) et qui a un indice de réfraction n_3 ($n_3 > n_1$) ;

de formation d'une couche métallique (3) sur ledit substrat (1) ;

de formation de façon sélective d'une couche de photorésist (4) sur ladite couche métallique (3) ;

d'élimination de manière sélective de ladite couche métallique (3) là où elle n'est pas masquée par ladite couche de photorésist (4) en utilisant une attaque à résonance de cyclotron électronique avec du gaz argon ;

d'élimination de ladite couche de photorésist (4) ;

de formation, par attaque, d'une nervure sur ledit substrat (1) en utilisant ladite couche métallique (3) comme masque (3a) par attaque à résonance de cyclotron électronique en utilisant un hydrocarbure fluoré gazeux ;

de formation, sur un bord latéral de ladite couche de guide d'onde optique (2), d'une couche d'échange de protons (5) qui est destinée à être utilisée comme un premier conduit de guide d'onde (2a, 2c) et qui a un indice de réfraction n_2 ($n_2 > n_3 > n_1$), par traitement à chaud dans une solution aqueuse capable d'échanger des protons avec des parties de guide d'onde optique qui sont mises à nu par élimination de ladite couche métallique (3) ; et,

d'élimination des parties restantes de ladite couche métallique (3).

3. Procédé de fabrication d'un dispositif de conversion de longueur d'onde optique selon la revendication 1, comprenant les étapes :

de formation, sur un substrat (1), fait d'une matière optique non linéaire qui a un indice de réfraction n_1, par diffusion de titane, d'une couche de guide d'onde optique (1_{Ti}) qui est destinée à être utilisée comme un second conduit de guide d'onde (2b) et qui a un indice de réfraction n_3 ($n_3 > n_1$) ;

de formation d'une couche métallique (3) sur ledit substrat (1) ;

de formation de façon sélective d'une couche de photorésist (4) sur ladite couche métallique (3) ;

d'élimination de manière sélective d'une partie de ladite couche métallique (3) et de ladite couche de guide d'onde optique (2), en utilisant ladite couche de photorésist (4) comme masque ;

de formation, sur un bord latéral de ladite couche de guide d'onde optique (2), d'une couche d'échange de protons (5) qui est destinée à être utilisée comme un premier conduit de guide d'onde (2a, 2c) et qui a un indice de réfraction n_2 ($n_2 > n_3 > n_1$), par traitement à chaud dans une solution aqueuse capable d'échanger des protons avec des parties de guide d'onde optique qui sont mises à nu par élimination de ladite couche métallique (3) ;

d'attaque de ladite couche d'échange de protons (5) pour en faire une couche mince par attaque d'ions réactifs en utilisant de manière sélective, comme masque (3a), les parties non éliminées de ladite couche métallique (3) ; et,

d'élimination des parties restantes de ladite couche métallique (3).

FIG. 1

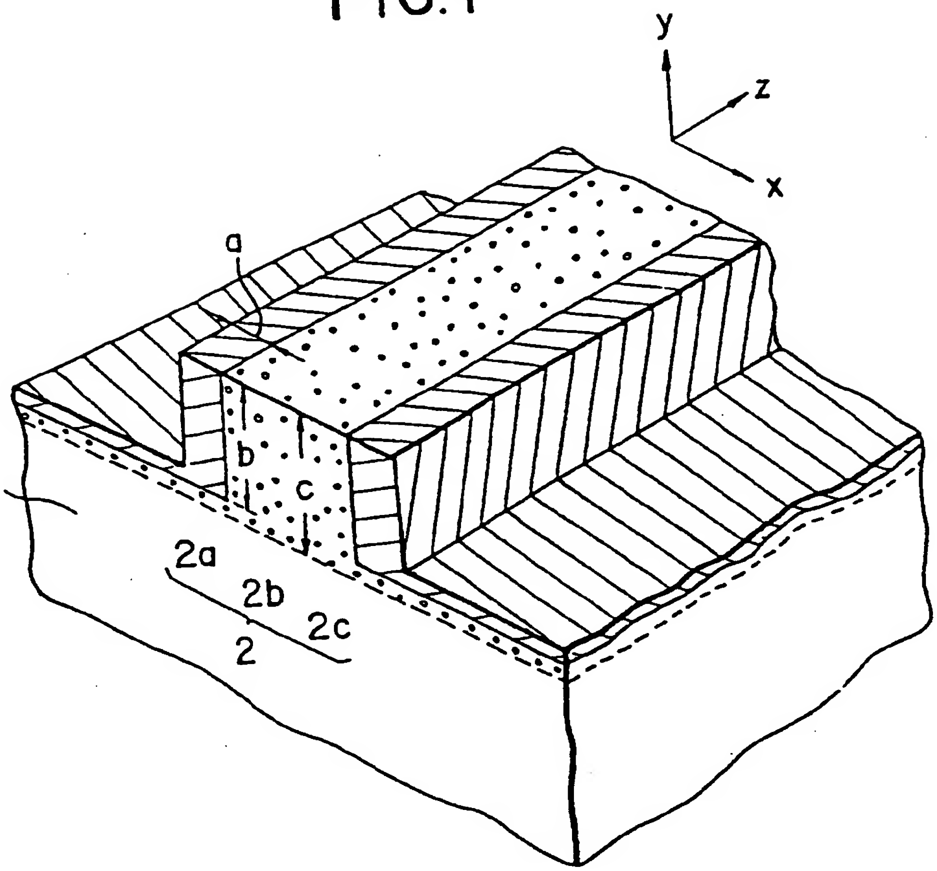

FIG. 2

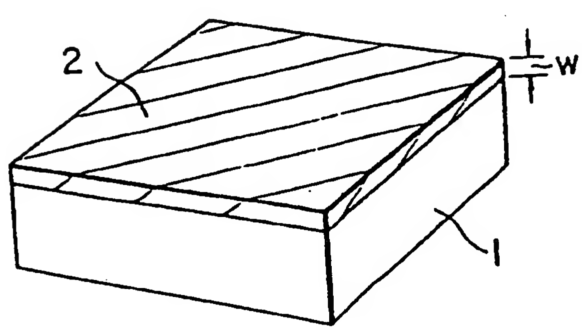

FIG. 3

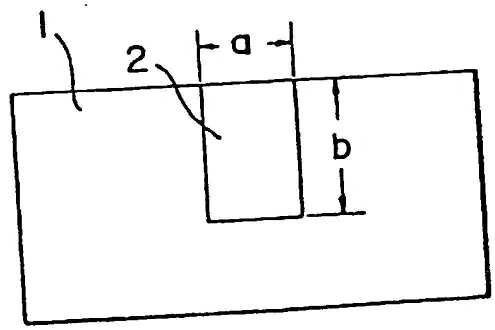

FIG. 4A

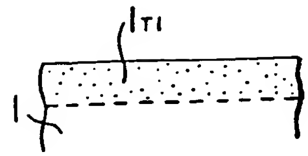

FIG. 4B

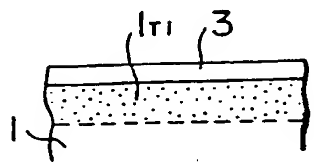

FIG. 4C

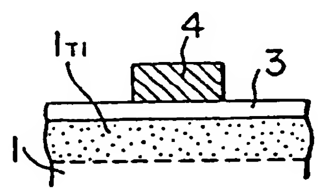

FIG. 4D

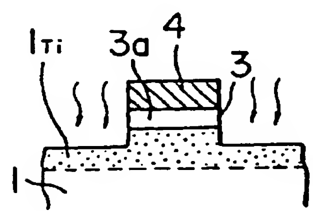

FIG. 4E

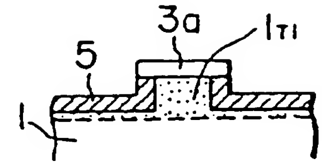

FIG. 4F

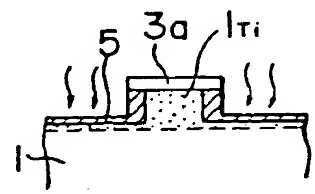

FIG. 4G

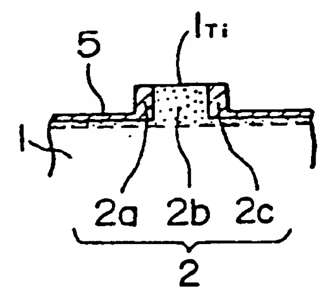

FIG. 5

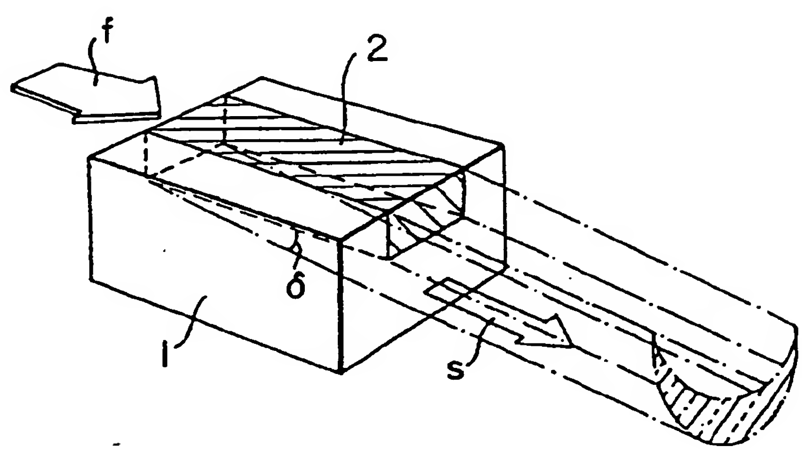

FIG. 6